Paper Abstract for CIRFFSS '94

Paper Title: Technology Development for Robotic Surface Inspection

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Technology Track: Robotic Sensing, Vision, and Perception

Application Track: **Space**

For the past three years at JPL, NASA has been sponsoring the *Remote Surface Inspection Project* to develop the technology needed for doing periodic and on-demand inspection of space borne platforms, in particular Space Station Freedom. The resultant system is comprised of three main components: robot manipulator control, teleoperated/automated multi-sensor inspection, and a graphical user interface to both of these. Key technology items include: methods for automated visual inspection; the development of an Integrated Sensor End-Effector which encompasses vision, proximity, temperature, and gas information to monitor the environment; and a high fidelity simulation of orbital inspection conditions. In this paper, each of these will be described as well as the issues which they successfully address. An overview of the entire inspection system will also be provided to show how the these technological innovations mesh with the system in philosophy and practice.

Visual Inspection By far, the largest effort in processing of this sensory information has been dedicated to computer vision techniques. We describe selected technology items that are incorporated into a research system for inspection that is to be used for visually detecting damage to orbiting space platforms. This application is especially challenging because of the harsh solar lighting in orbit, complex reflective objects, the small sizes of flaws caused by micro-meteorite impacts, the need for efficient computer processing, and communication limitations in sending data back to earth.

The general problem consists of locating and characterizing flaw induced changes between an earlier reference template image and a new inspection image. In the absence of noise, viewpoint differences, lighting variations, and benign changes, the detection of significant flaw damage could be obtained by a process of simple subtraction. However, in our inspection application each of the above mentioned factors complicates the identification of the change.

The main challenges to overcome are that of correcting for misregistration of the images, and performing an efficient interpretation of the information in the images. We have developed a near real-time local correlation based search technique to match as much of the reference and inspection images as possible. A gradient based iterative warping technique is used for the simultaneous registration of reference/inspection images as well as flaw detection. The algorithm adopts a hierarchical correlation approach in which it iteratively (coarse to fine) modifies image warp parameters to maximally correlate the reference and inspection images - any remaining uncorrelated regions of the image are then flagged as potential flaws.

We have also exploited the idea of how visual information has a "bell-shaped" distribution across scale. This idea has a strong implication to the design of telerobotic surface inspection algorithms. What it says is that surface features are visible or detectable only over a limited band of scale - that is if one is searching for "trees" in a forest, the trees will be discernible only at the right. An approach to designing algorithms to automatically select the "correct" scale is presented.

Other Inspection Senses In addition to visual sensing, we have recently incorporated the extended capabilities of non-contact proximity, temperature, and gas measurement. All three capabilities are achieved with commercial sensors, physically and electrically integrated into a compact end-effector. This end-effector also provides lighting of constant and measured intensity, short duration flashes, parallel jaw gripping, and six degrees-of-freedom force sensing.

Proximity sensing is achieved with two infra-red triangulation sensors, sensitive to approximately 0.75m. The distance measurements are used for collision avoidance, surface contour following, and surface contour measuring. Temperature sensing is achieved with an infra-red optical pyrometer, sensitive to temperatures from 0 to 1000°F. Gas sensing is achieved with a multi-gas metal oxide semiconductor type sensor. While it may be possible to employ this gas sensing technology in orbit, we recognize the superiority of using a compact mass spectrometer in the ambient vacuum of space. Such a sensor has also been tested as part of this work.

Finally, the remaining components of the end effector, especially the lighting system, will be discussed in detail. The controlled lights are maintained at a known illumination level by a optical transistor feedback circuit. This makes the illumination independent of current fluctuations and bulb age, and makes precise measurement and camera characterization possible. This lighting is augmented by extremely compact and fast pulse strobes. The strobes provide short duration lighting of intensity on the order of the sun but only for short, energy saving, single camera frame, bursts. Since the flashes are mounted on the outside surface of the movable parallel jaws of the gripper, flash illumination angle may be varied as desired.

Space Platform Emulation To demonstrate the capabilities of the inspection system, a one-third scale mockup of the Space Station Freedom truss has been created. The mockup is outfitted with numerous defects: simulated micro-meteor impacts, missing screws, controllable hot and cold spots, and controllable gas leaks. Further, to make the inspection environment as realistic as possible, the area is darkened by black curtains, ceiling, and floor, and illuminated by a sophisticated solar illumination simulator. This simulator is a 1500 Watt arc lamp mounted on a four degrees-of-freedom, computer controlled platform. We have developed the kinematics of this system to enable the illumination angle of the scene can be varied at orbital rates, while maintaining a constant illumination flux, just as the sun provides.